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PERFORMANCE OF ILMENITE CONCRETE AT SUSTAINED ELEVATED TEMPERATURES

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PERFORMANCE OF ILMENITE CONCRETE AT SUSTAINED ELEVATED TEMPERATURES

by

H.S. Wilson*

ABSTRACT

Two similar concrete mixes were made with cement contents of about 350 kg/m^3 and a water-to-cement ratio of 0.50. The concrete specimens, moist cured for 7 days, were cured in air for 28 and 120 days respectively prior to heating. The exposure temperatures were 75, 150, 300, and 450°C. The periods of exposure at each temperature were 2, 30, and 120 days.

The compressive strengths, before heating, of the specimens cured for 35 and 120 days were 41.0 and 46.2 MPa respectively, and the flexural strengths were 4.9 and 5.8 MPa. Compared with those strengths, the strengths of the specimens heated for 30 days or more increased at 75° but decreased at higher temperatures. The losses increased with increase in temperature, reaching about 30% at 450°C.

The flexural strength of the concrete cured in air for 28 days was more adversely affected than was the compressive strength. The flexural and compressive strengths of the concrete cured in air for 120 days were affected to about the same degree. The longer curing period had little effect on the relative losses in compressive strength, but the longer curing period reduced the loss in flexural strength. In most applications, the loss in strength could be compensated by proportioning the mix to over-design for strength.

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PERFORMANCE DU BÉTON À ILMÉNITE EXPOSÉ À DE HAUTES TEMPÉRATURES PENDANT DE LONGUES PÉRIODES

par

H.S. Wilson*

RÉSUMÉ

Deux bétons semblables ont été constitués avec une masse de ciment d'environ 350 kg/m^3 et un rapport eau-ciment de 0,50. On les a conservés humides pendant 7 jours, puis ont les a fait durcir à l'air pendant 28 et 120 jours respectivement. Ensuite, on les a successivement exposés à des températures de 75, 150, 300 et 450°C, pendant 2, 30 et 120 jours.

Les résistances à la compression, avant chauffage, des bétons conservés pendant 35 et 120 jours sont estimées à 41 et 46,2 MPa respectivement, et les résistances à la flexion, à 4,9 et 5,8 MPa respectivement. En comparaison, les résistances des spécimens chauffés pendant 30 jours ou plus sont meilleures à 75°, mais se dégradent à des températures supérieures. Les pertes augmentent avec la température, pour atteindre environ 30 % à 450°C.

La résistance à la flexion du béton conservé à l'air pendant 28 jours diminue davantage que la résistance à la compression. Les résistances à la flexion et à la compression du béton conservé à l'air pendant 120 jours se dégradent à peu près dans les mêmes proportions. Une augmentation de la période de durcissement a peu d'effets sur la perte relative de résistance à la compression, mais elle réduit la perte de résistance à la flexion. Dans la plupart des applications, il est possible de compenser la perte de résistance en modifiant la composition du mélange.

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INTRODUCTION

This study is a continuation of a research project begun in 1979 to investigate the effect of sustained elevated temperatures on concretes incorporating different cementing materials and different aggregates. The first phase of the study dealt with the performance of concrete containing normal portland cement, normal portland cement plus granulated blast furnace slag, and normal portland cement plus fly ash. In the second phase the performance of concretes containing dolostone aggregate and limestone aggregate with normal portland cement were compared. Exposure temperatures were in the range of 75 to 600°C. Results of these two phases of the study have been reported previously (1,2). It was concluded that:

(a) In general, the incorporation of fly ash and slag in concretes had little effect on the mechanical properties of the concretes regardless of the exposure temperature or the ratio of water-to-cementitious material.
(b) The significant changes in the mechanical properties of the concretes occurred within the first 30 days of exposure.
(c) Both phases revealed the dolostone aggregate to be unstable after exposure for 30 days at 150°C. This leads to disruption of the concrete specimens. This instability was attributed to slow oxidation of pyrite contained in some of the aggregate particles, resulting in expansion of the aggregate. Limestone aggregate under similar conditions was not affected.
(d) Except for the above, reductions in compressive strength were generally independent of the aggregate and mostly proportional to the exposure temperature. At temperatures above 150°C, the reduction in strength was proportional to the exposure period.
(e) Regardless of temperature and duration of exposure the leaner concretes were slightly less affected than were the richer concretes.

The study reported herein was concerned with the effect of exposures to temperatures between 75 and 450°C on concretes incorporating high density ilmenite aggregates and normal portland cement.

SCOPE

Two equivalent concrete mixes were prepared with identical cement contents and water-cement ratios. From each mix, 60 cylinders, 102 by 203 mm and 36 prisms, 76 by 102 by 406 mm were made. The specimens made from the

first mix were moist-cured for 7 days, and air-cured for 28 days before being placed in the kilns (mix A). The specimens made from the second mix were moist-cured for 7 days and air-cured for 120 days before being placed in the kilns (mix B). The specimens made from both mixes were exposed to temperatures of 75, 150, 300, and 450°C for periods of 2, 30, and 120 days. Before and at the end of the exposure periods, mechanical properties, such as weight, pulse velocity and resonant frequency were determined.

CONCRETE MIXES

Because of the high relative density of the aggregates and the limited capacity of the concrete mixer, each mix was prepared in four similar batches, of 0.08 m^3 each.

MATERIALS

Cement

A commercially-available normal portland cement ASTM Type 1 (CSA Type 10) was used in all mixes. The physical properties and chemical analysis of the cement are shown in Table 1.

Aggregates

Both coarse and fine aggregates were ilmenite obtained from a supplier in eastern Canada. They were received in two lots, one for each of the two mixes. They were used "as received" without altering the gradings. The gradings and the physical properties are shown in Tables 2 and 3.

Mix Proportions and Properties of Fresh Concrete

The detailed mix proportions of each of the four batches of the two mixes are shown in Tables 4 and 11. No air-entraining agent was used. The properties of the fresh concrete from each batch are also shown in Tables 4 and 11.

PREPARATION AND CURING OF TEST SPECIMENS

Moulds were filled in two layers; compaction was done by external vibration because the density of the aggregate was too high to use rodding or internal vibration.

The specimens were cured in the moulds at about 20°C for 24 h. After removing from the moulds the 1-day densities were determined. They then were placed in a moist-curing room for 6 days at a temperature of 23 ± 1.7°C and 100% relative humidity. They were subsequently air dried at a temperature of 23 ± 1.1°C and 50% relative humidity until being placed in the kilns. At 14 days, two prisms from each mix were broken to determine the flexural strength and at 28 days, two cylinders of each mix were broken to determine the compressive strength. Subsequent to the flexural strength tests, one broken one-half of each prism was placed in a special jig and a compressive load was applied to a 76 by 102 mm area to determine the modified cube compressive strength.

The specimens made from mix A were air dried for 28 days and those made from mix B were air dried for 120 days before being placed in the kilns. Before they were placed in the kilns, the following properties were determined: weight, pulse velocity, resonant frequency, and compressive strength.

HEATING EQUIPMENT

The four electrically-heated kilns had internal dimensions of about 0.9 by 1.2 by 1.8 m. The exposed heating elements had been installed in the door and the three walls. They were divided into three zones vertically so that the temperature could be controlled and the variation minimized. The specimens were grouped into two levels close to the centre of the kiln to further reduce variation of temperature between specimens. Temperatures were monitored by four chromel-alumel thermocouples in each kiln, connected to a multi-point recorder. The variation in the temperatures of the specimens was ±5°C.

HEATING OF SPECIMENS

The same procedure was followed for the specimens air dried for 28 and for 120 days.

Three cylinders and two prisms were placed in each kiln and the kilns were heated to the desired temperatures of 75, 150, 300, and 450°C at a rate of 25°C/h to 150°C and of 50°C/h above 150°C. At the end of 48 h, the kilns were turned off and the specimens were removed. The kilns heated to 300 and 450°C were allowed to cool before the specimens were removed, to prevent thermal shocking of the specimens and to allow safe handling.

The kilns were each reloaded with six cylinders and four prisms and reheated to the previous temperature. Three cylinders and two prisms were removed after heating for 30 and 120 days. As was done previously, the kilns heated to 300 and 450°C were allowed to cool before the specimens were removed.

Reference specimens (three cylinders and two prisms) from each of the two mixes, cured in the same way as the test specimens, were tested before heating and at the end of the 120 day heating period.

Measurements done before and after heating the specimens from mix A are shown in Tables 5 to 10, and of specimens from mix B are shown in Tables 12 to 17.

The relative effects of heating to the various temperatures on the weight, compressive and flexural strengths pulse velocity and resonant frequency are shown graphically in Fig. 1 to 10.

DISCUSSION OF RESULTS

Although test specimens from mix A were air-dried for 28 days and the specimens from mix B were air-dried for 120 days, the maximum losses in weight of specimens from both mixes during heating was about 3%. At 75°C, less than 1% weight was lost during the 2-day heating period, and about 2% during the 30- and 120-day heating periods. At higher temperatures, weight loss increased with temperatures. The losses were virtually complete after 2 days heating.

The compressive strengths of the specimens from both mixes heated to 75°C decreased initially, possibly because of differential moisture content and empty pore spaces due to partial drying. The strength then increased as

heating continued because of accelerated hydration of the unhydrated cement. When heated to 150°C, the strength of the specimens, conditioned for 35 days, again increased initially because of accelerated hydration. The strengths then decreased, probably because of the commencement of micro-cracking. The specimens conditioned for 127 days showed the same pattern, but the initial strength was lower because there was less unhydrated cement to be affected. At higher temperatures the strengths were progressively lower as micro-cracking continued. The specimens conditioned for 127 days lost a higher proportion of strength at the higher temperatures than did those conditioned for 35 days. The former specimens had higher strength at initiation of heating and consequently, after heating, the specimens from both mixes had similar strengths.

Both pulse velocities and resonant frequencies decreased progressively with increase of exposure temperature. This began at 75°C, at which temperature specimens had increased in strength. The decreases in pulse velocity and resonant frequency at that temperature are probably due to the evaporation of uncombined water leaving empty pore space. At higher temperatures, losses were probably due to the progressive development of micro cracks. The decrease in pulse velocity and resonant frequency at 300 and 450°C correspond to the decreases in flexural strength. The specimens conditioned for the longer period lost less than did those cured for the shorter period.

CONCLUDING REMARKS

The compressive and flexural strengths of concretes containing ilmenite aggregates increased when the concretes were exposed to a sustained temperature of 75°C for 30 days or longer. At higher temperatures the compressive and flexural strengths decreased progressively with temperature.

In actual application, the strength loss would need to be compensated for in the mix proportions by designing for strengths of up to 30% above the desired service strength, dependent on the exposure temperature.

The conditioning periods of 28 and 120 days did not have any marked effect on the compressive strengths. The longer period appeared to have a detrimental effect on the flexural strength at the lower temperatures but a beneficial effect at the higher temperatures.

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REFERENCES

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2. Carette, G.G. and Malhotra, V.M. "Performance of dolostone and limestone concretes at sustained high temperatures"; Division Report MRP/MSL 82-97; CANMET, Energy, Mines and Resources Canada; 1982.

Table 1 - Physical properties and chemical analysis of the cement*

Description of test		
Physical tests - general		
Time of set (Vicat Needle):	Initial ...	2 h 04 min
	Final	3 h 52 min
Fineness:	No. 200 (passing)	97.0%
	No. 325 (passing)	85.9%
Surface area, Blaine		352 m^2/kg
Soundness - Autoclave		0.001%
Physical tests - mortar strength		
Compressive strength of 51-mm cubes at:		
3-day		22.7 MPa
7-day		30.6 MPa
28-day		39.8 MPa
Chemical analysis		
Silicon dioxide (SiO_2)		21.54%
Aluminum oxide (Al_2O_3)		4.84%
Ferric oxide (Fe_2O_3)		2.10%
Calcium oxide (CaO) total		64.10%
Magnesium oxide (MgO)		2.30%
Sulphur trioxide (SO_3)		3.97%
Loss on ignition		0.73%
Insoluble residue		0.14%
Others		0.28%

*Manufacturer's data.

Table 2 - Grading of aggregates

Coarse aggregates		Fine aggregate	
Sieve size	Cumulative per cent retained	Sieve size	Cumulative per cent retained
19.0 mm	6.4	4.75 mm	0.1
12.5 mm	35.6	2.38 mm	15.1
9.5 mm	58.8	1.19 mm	36.5
4.75 mm	93.0	600 µm	53.6
2.38 mm	97.9	300 µm	70.8
1.19 mm	98.2	150 µm	84.9

Table 3 - Physical properties of aggregates

	Coarse aggregate	Fine aggregate
Bulk specific gravity (SSD)*	4.16	4.41
Absorption, %	0.1	0.8

*Saturated surface dry

Table 4 - Mix proportions and properties of fresh concrete: mix A

Batch No.	W/C	Agg/Cem	Mix proportions Quantities, kg/m^3 Cement	Coarse Agg	Fine Agg	Properties of fresh concrete Temp. °C	Slump mm	Unit weight kg/m^3	Air content %
1	0.50	8.62	348	1577	1424	20	64	3522	2.2
2	0.50	8.62	349	1580	1427	20	76	3529	2.3
3	0.50	8.63	351	1592	1437	20	64	3554	2.0
4	0.50	8.62	347	1572	1419	19	64	3509	2.3

Table 5 - Densities of specimens at 24 h: mix A

Batch No.	Number of specimens	Density, kg/m^3
1	16 prisms	3573
	3 cylinders	3566
2	2 prisms	3596
	27 cylinders	3569
3	16 prisms	3568
	3 cylinders	3570
4	2 prisms	3547
	27 cylinders	3550
Averages	prisms	3571
	cylinders	3564

Table 6 - Non-destructive tests of specimens* after 7-days moist curing: mix A

Batch No.	Weight, kg	Pulse velocity, m/s	Resonant frequency, Hz
1	11.469	4336	4723
2	5.814	4537	-
3	11.469	4278	4661
4	5.804	4443	-

*Averages of 16 prisms and 24 cylinders

Table 7 - Strength of specimens exposed to heat: mix A

Specimen type	Time of exposure, days	Compressive strength,[1] MPa	Flexural strength,[2] MPa	Modified cube strength,[3] MPa
At 75°C				
prisms	2	-	3.9	41.3
cylinders	2	37.6	-	-
prisms	30	-	6.0	55.7
cylinders	30	48.7		
prisms	120	-	6.0	56.2
cylinders	120	47.8	-	-
At 150°C				
prisms	2	-	5.4	51.6
cylinders	2	46.1	-	-
prisms	30	-	5.2	53.4
cylinders	30	43.6	-	-
prisms	120	-	5.8	55.8
cylinders	120	42.7	-	-
At 300°C				
prisms	2	-	4.5	47.9
cylinders	2	39.8	-	-
prisms	30	-	3.8	44.9
cylinders	30	36.4	-	-
prisms	120	-	3.7	39.1
cylinders	120	33.2	-	-

Table 7 (Cont'd)

Specimen type	Time of exposure, days	Compressive strength,[1] MPa	Flexural strength,[2] MPa	Modified cube strength,[3] MPa
At 450°C				
prisms	2	-	3.7	46.5
cylinders	2	33.3	-	-
prisms	30	-	2.8	43.3
cylinders	30	30.7	-	-
prisms	120	-	2.5	41.0
cylinders	120	32.3	-	-

[1]Strength before heating: 41.0 MPa (average of 6 cylinders)

[2]Strength before heating: 4.9 MPa (average of 4 prisms)

[3]Strength before heating: 45.7 MPa (average of 4 prisms)

Table 8 - Non-destructive tests of specimens exposed to heat: mix A

Specimen type	At initiation of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz	Type of exposure, days	At termination of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz
At 75°C							
prisms	11.325	4314	4700	2	11.218	4069	4340
cylinders	5.740	4638	-	2	5.692	4347	-
prisms	11.262	4328	4720	30	11.077	3836	4315
cylinders	5.724	4565	-	30	5.601	4007	-
prisms	11.383	4329	4710	120	11.135	3842	4300
cylinders	5.657	4582	-	120	5.532	3996	-
At 150°C							
prisms	11.255	4330	4675	2	10.967	3683	4065
cylinders	5.700	4572	-	2	5.561	3837	-
prisms	11.390	4350	4710	30	11.102	3531	3950
cylinders	5.680	4565	-	30	5.535	3755	-
prisms	11.420	4402	4770	120	11.132	3639	4065
cylinders	5.684	4572	-	120	5.538	3776	-
At 300°C							
prisms	11.405	4276	4660	2	11.065	3199	3585
cylinders	5.793	4511	-	2	5.617	3346	-
prisms	11.357	4288	4665	30	11.017	3023	3400
cylinders	5.717	4525	-	30	5.540	3195	-
prisms	11.332	4307	4640	120	11.010	3009	3350
cylinders	5.717	4525	-	120	5.549	3133	-

Table 8 (Cont'd)

Specimen type	At initiation of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz	Time of exposure, days	At termination of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz
At 450°C							
prisms	11.430	4348	4750	2	11.055	2596	2965
cylinders	5.722	4475	-	2	5.521	2683	-
prisms	11.310	4317	4705	30	10.937	2385	2715
cylinders	5.693	4485	-	30	5.500	2540	-
prisms	11.312	4324	4695	120	10.955	2319	2550
cylinders	5.680	4518	-	120	5.493	2279	-

[1]Pulse velocity

[2]Resonant frequency

Table 9 - Strength properties of reference specimens: mix A

Batch No.	Compressive, MPa 28 days	Flexural, MPa 14 days	Compressive, MPa 35 days	Flexural, MPa 35 days	Compressive, MPa 155 days	Flexural, MPa 155 days
1	38.8	4.5	-	4.7	-	5.6
2	39.5	-	40.5	-	45.4	-
3	38.7	4.2	-	5.0	-	5.8
4	38.3	-	41.5	-	45.5	-
Average	38.8	4.4	41.0	4.8	45.5	5.7

Table 10 - Non-destructive tests of reference specimens: mix A

Batch No.	Weight, kg	PV, m/s	RF, Hz	Weight, kg	PV, m/s	RF, Hz
	35 days			155 days		
1	11.367	4372	4725	11.288	4269	4675
2	5.704	4548	-	5.700	4528	-
3	11.275	4288	4660	11.195	4295	4640
4	5.650	4521	-	5.610	4535	-

Table 11 - Mix proportions and properties of fresh concrete: mix B

Batch No.	W/C	Agg/Cem	Mix proportions Quantities, kg/m^3 Cement	Coarse Agg	Fine Agg	Properties of fresh concrete Temp. °C	Slump mm	Unit weight kg/m^3	Air content %
5	0.50	8.5	359	1590	1464	23	89	3593	1.9
6	0.50	8.5	360	1594	1467	23	83	3599	1.9
7	0.50	8.5	359	1590	1464	21	95	3593	1.6
8	0.50	8.5	358	1588	1462	22	95	3586	1.8

Table 12 - Densities of specimens at 24 h: mix B

Batch No.	Number of specimens	Density, kg/m^3
5	16 prisms	3637
	3 cylinders	3641
6	2 prisms	3616
	27 cylinders	3636
7	16 prisms	3628
	3 cylinders	3621
8	2 prisms	3589
	27 cylinders	3593
Averages	prisms	3618
	cylinders	3623

Table 13 - Non-destructive tests of specimens* after 7-days moist curing: mix B

Batch No.	Weight, kg	Pulse velocity, m/s	Resonant frequency, Hz
5	11.105	4503	4920
6	5.915	4402	-
7	11.041	4415	4845
8	5.871	4321	-

* Averages of 16 prisms and 24 cylinders

Table 14 - Strength of specimens exposed to heat: mix B

Specimen type	Time of exposure, days	Compressive strength,[1] MPa	Flexural strength,[2] MPa	Modified cube strength,[3] MPa
At 75°C				
prisms	2	-	4.4	45.2
cylinders	2	40.7	-	-
prisms	30	-	6.7	54.3
cylinders	30	49.0	-	-
prisms	120	-	5.9	53.4
cylinders	120	48.7	-	-
At 150°C				
prisms	2	-	5.2	53.2
cylinders	2	44.5	-	-
prisms	30	-	6.0	54.3
cylinders	30	45.7	-	-
prisms	120	-	5.3	57.1
cylinders	120	42.3	-	-
At 300°C				
prisms	2	-	5.1	47.5
cylinders	2	39.6	-	-
prisms	30	-	5.1	50.0
cylinders	30	41.8	-	-
prisms	120	-	5.2	48.3
cylinders	120	36.1	-	-

Table 14 (Cont'd)

Specimen type	Time of exposure, days	Compressive strength,[1] MPa	Flexural strength,[2] MPa	Modified cube strength,[3] MPa
At 450°C				
prisms	2	-	4.7	46.2
cylinders	2	33.9	-	-
prisms	30	-	4.0	47.3
cylinders	30	30.9	-	-
prisms	120	-	3.9	46.8
cylinders	120	30.7	-	-

[1]Strength before heating: 46.2 MPa (average of 6 cylinders)

[2]Strength before heating: 5.8 MPa (average of 4 prisms)

[3]Strength before heating: 46.6 MPa (average of 4 prisms)

Table 15 - Non-destructive tests of specimens exposed to heat: mix B

Specimen type	At initiation of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz	Time of exposure, days	At termination of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz
At 75°C							
prisms	10.915	4540	4900	2	10.833	4260	4600
cylinders	5.822	4450	-	2	5.776	4222	-
prisms	10.918	4546	4950	30	10.728	4063	4500
cylinders	5.827	4473	-	30	5.730	4019	-
prisms	10.868	4504	4840	120	10.673	3965	4400
cylinders	5.834	4435	-	120	5.732	3920	-
At 150°C							
prisms	10.873	4506	4850	2			
cylinders	5.810	4437	-	2			
prisms	10.798	4559	4860	30	10.563	3805	4180
cylinders	5.777	4456	-	30	5.662	3695	-
prisms	10.900	4546	4915	120	10.658	3783	4175
cylinders	5.807	4450	-	120	5.682	3642	-
At 300°C							
prisms	10.778	4627	4820	2	10.415	3490	3875
cylinders	5.801	4339	-	2	5.637	3333	-
prisms	10.670	4452	4845	30	10.415	3444	3800
cylinders	5.775	4401	-	30	5.637	3361	-
prisms	10.898	4480	4925	120	10.623	3361	3800
cylinders	5.699	4361	-	120	5.558	3241	-

Table 15 (Cont'd)

Specimen type	At initiation of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz	Time of exposure, days	At termination of heating: Weight, kg	PV,[1] m/s	RF,[2] Hz
At 450°C							
prisms	10.813	4522	4910	2	10.488	3054	3450
cylinders	5.728	4364	-	2	5.560	2900	-
prisms	10.885	4488	4875	30	10.568	2826	3100
cylinders	5.750	4345	-	30	5.588	2551	-
prisms	10.803	4480	4850	120	10.503	2823	3025
cylinders	5.781	4327	-	120	5.623	2581	-

[1]Pulse velocity

[2]Resonant frequency

Table 16 - Strength properties of reference specimens: mix B

Batch No.	Compressive, MPa 28 days	Flexural, MPa 14 days	Compressive, MPa 127 days	Flexural, MPa 127 days	Compressive, MPa 247 days	Flexural, MPa 247 days
5	31.7	-	-	5.6	-	6.4
6	31.8	5.2	47.0	-	44.7	-
7	34.8	-	-	6.0	-	6.5
8	33.4	5.1	45.4	-	44.0	-
Average	32.9	5.2	46.2	5.8	44.4	6.5

Table 17 - Non-destructive tests of reference specimens: mix B

Batch No.	Weight, kg	PV, m/s	RF, Hz	Weight, kg	PV, m/s	RF, Hz
	127 days			247 days		
5	10.808	4519	4890	10.728	4404	4800
6	5.808	4379	-	5.770	4284	-
7	10.853	4498	4880	10.773	4375	4825
8	5.754	4367	-	5.713	4219	-

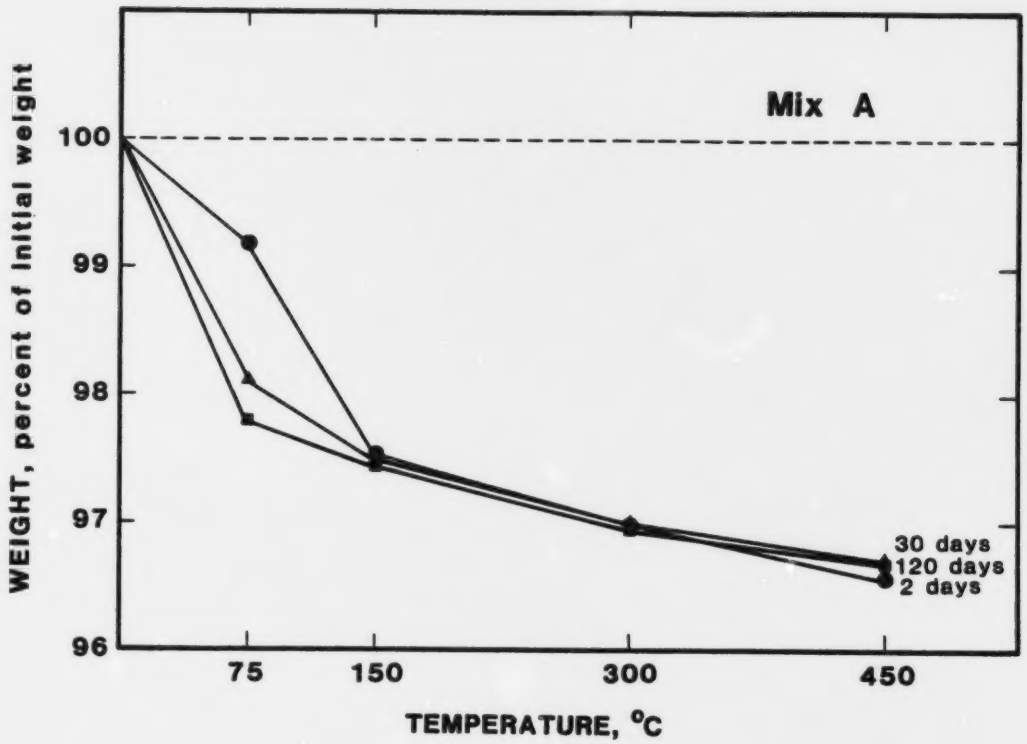

Fig. 1 - Change in weight during heating: mix A

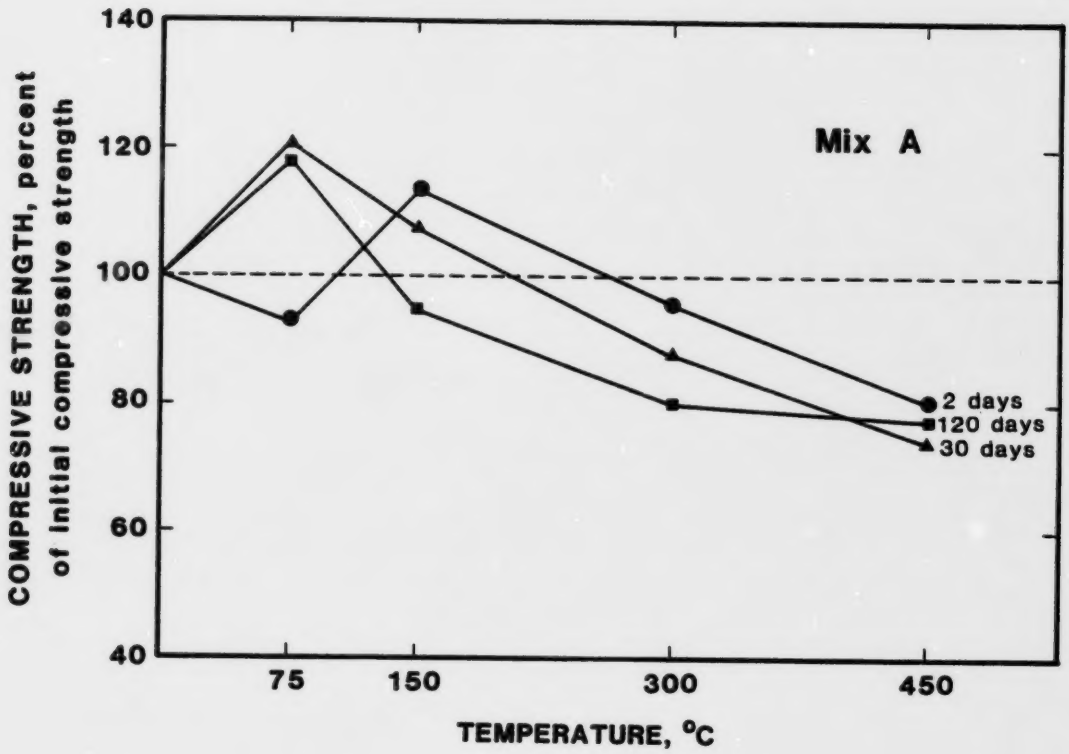

Fig. 2 - Change in compressive strength during heating: mix A

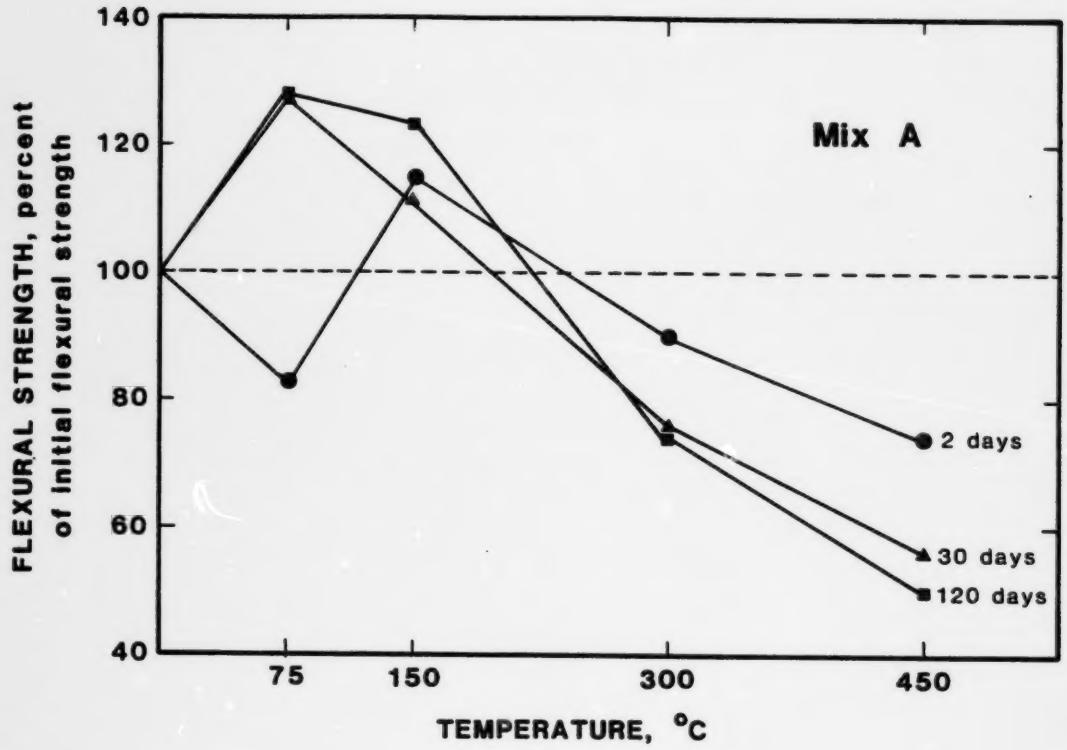

Fig. 3 - Change in flexural strength during heating: mix A

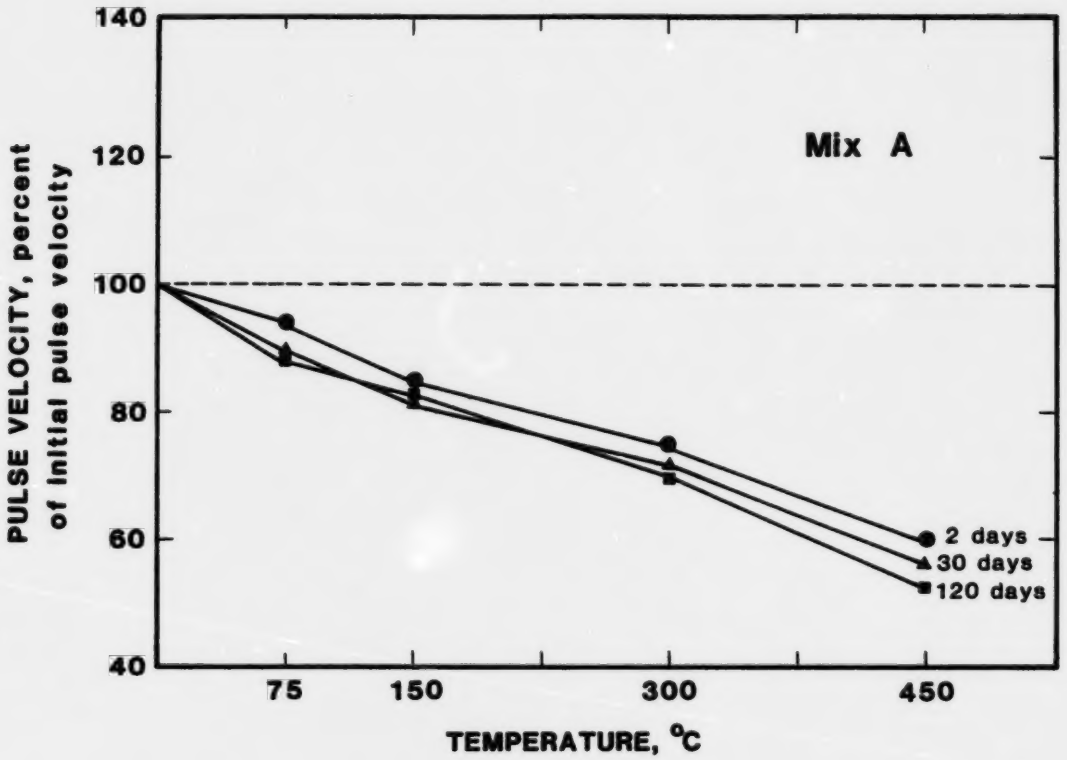

Fig. 4 - Change in pulse velocity during heating: mix A

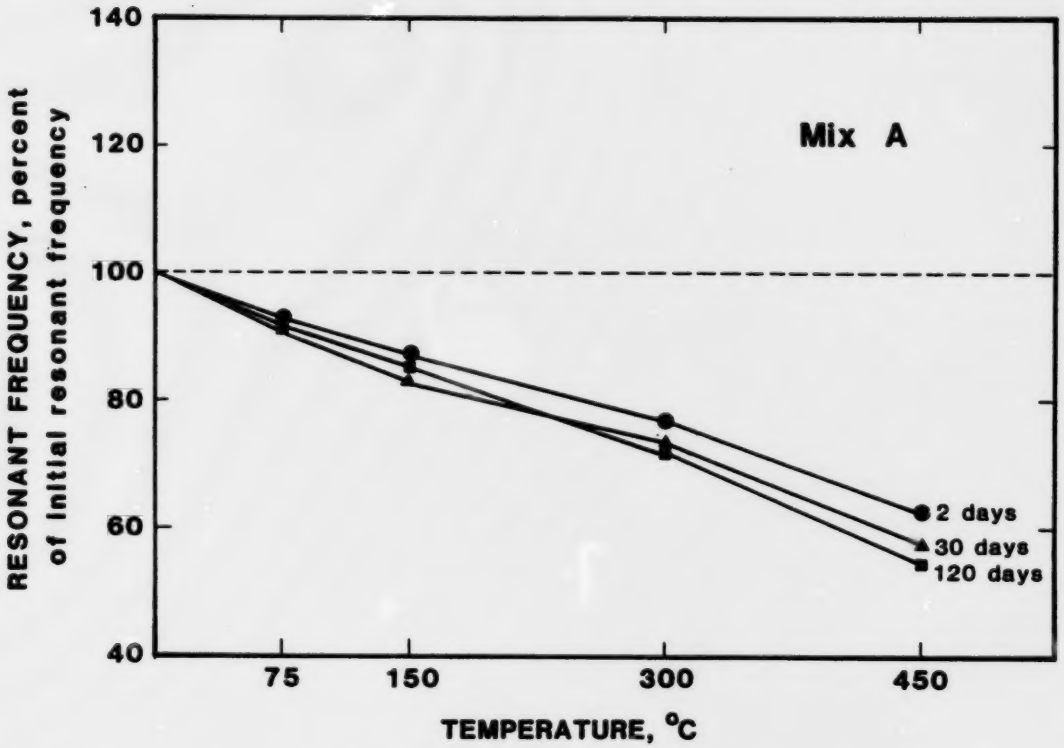

Fig. 5 - Change in resonant frequency during heating: mix A

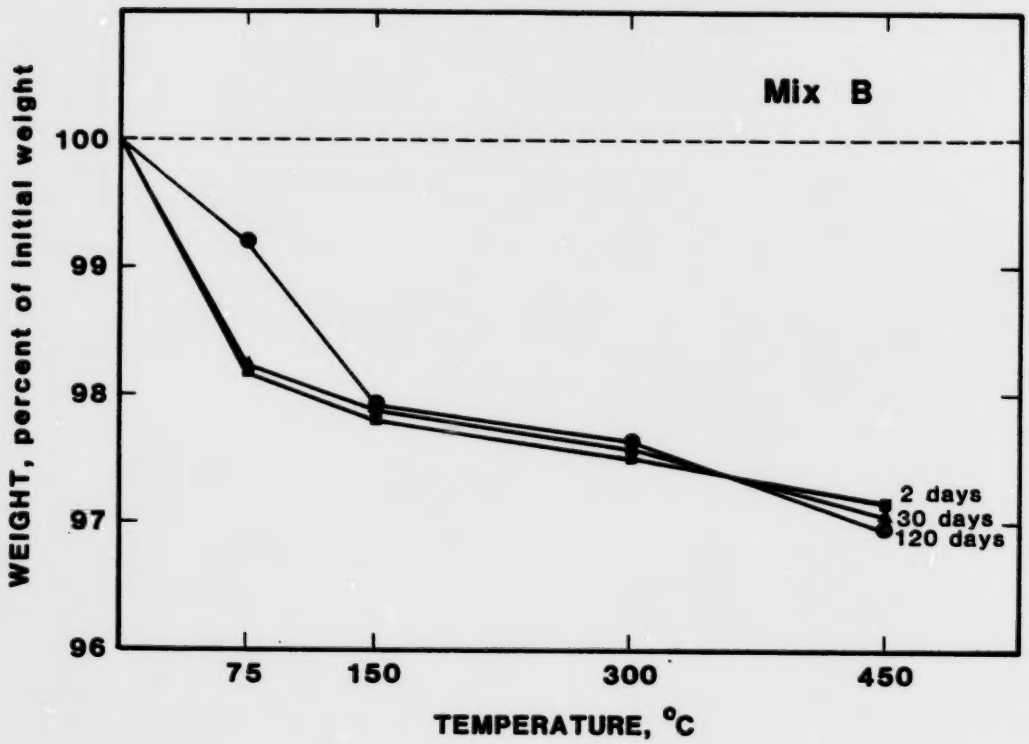

Fig. 6 - Change in weight during heating: mix B

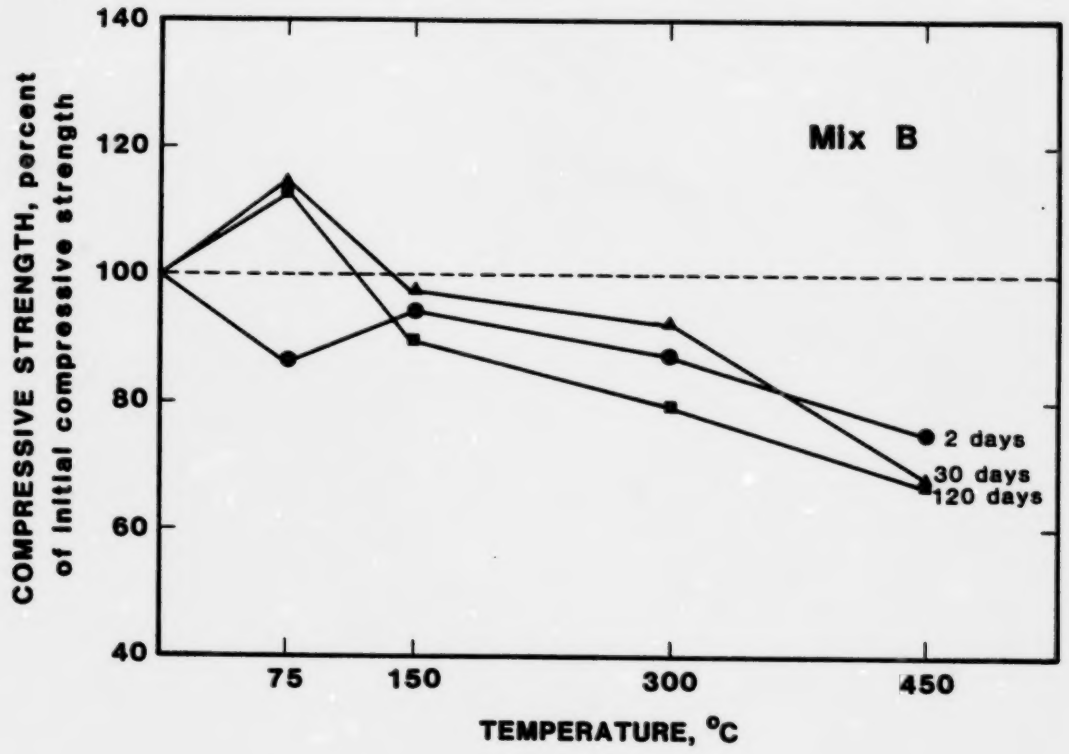

Fig. 7 - Change in compressive strength during heating: mix B

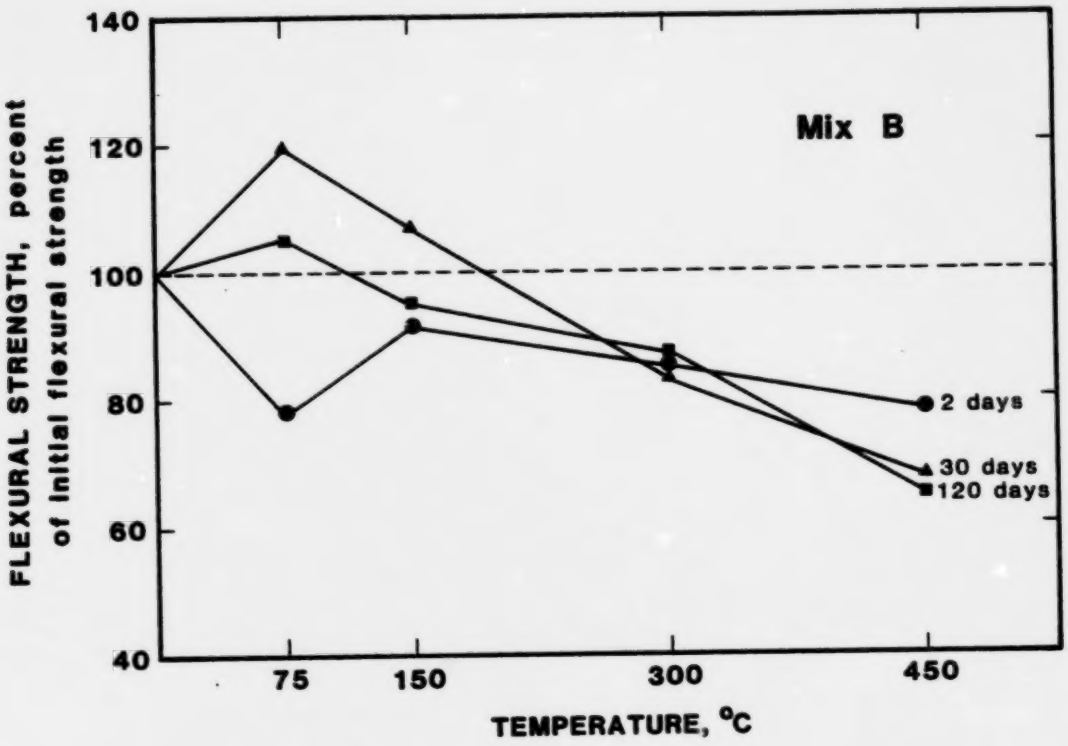

Fig. 8 - Change in flexural strength during heating: mix B

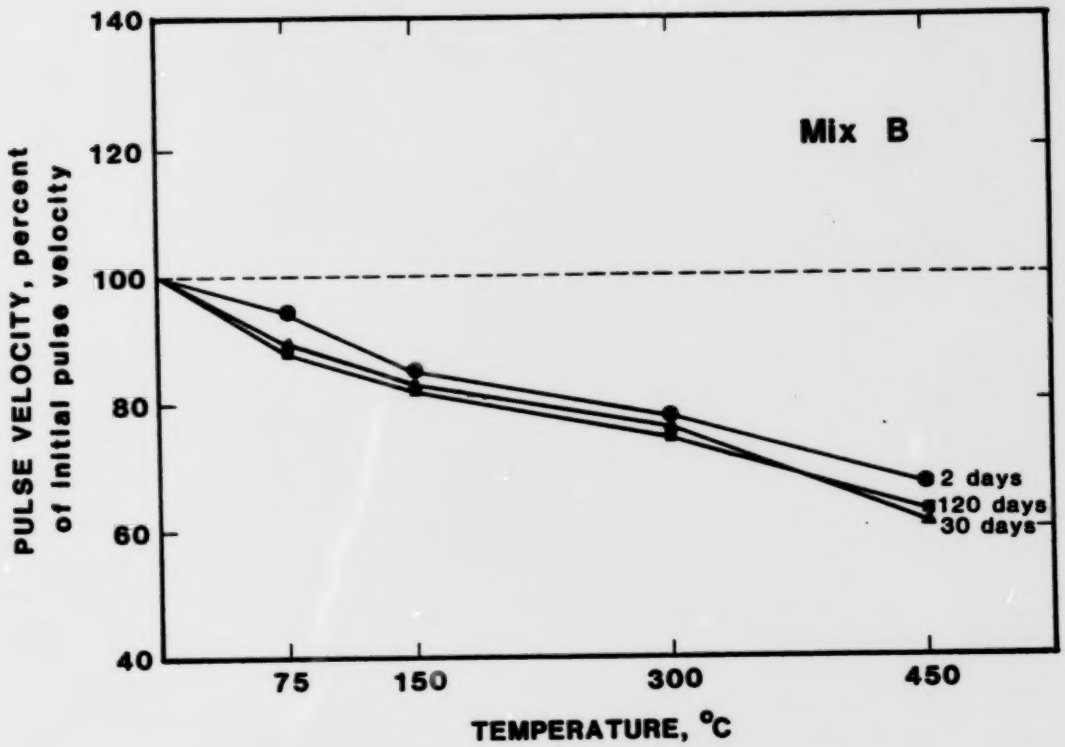

Fig. 9 - Change in pulse velocity during heating: mix B

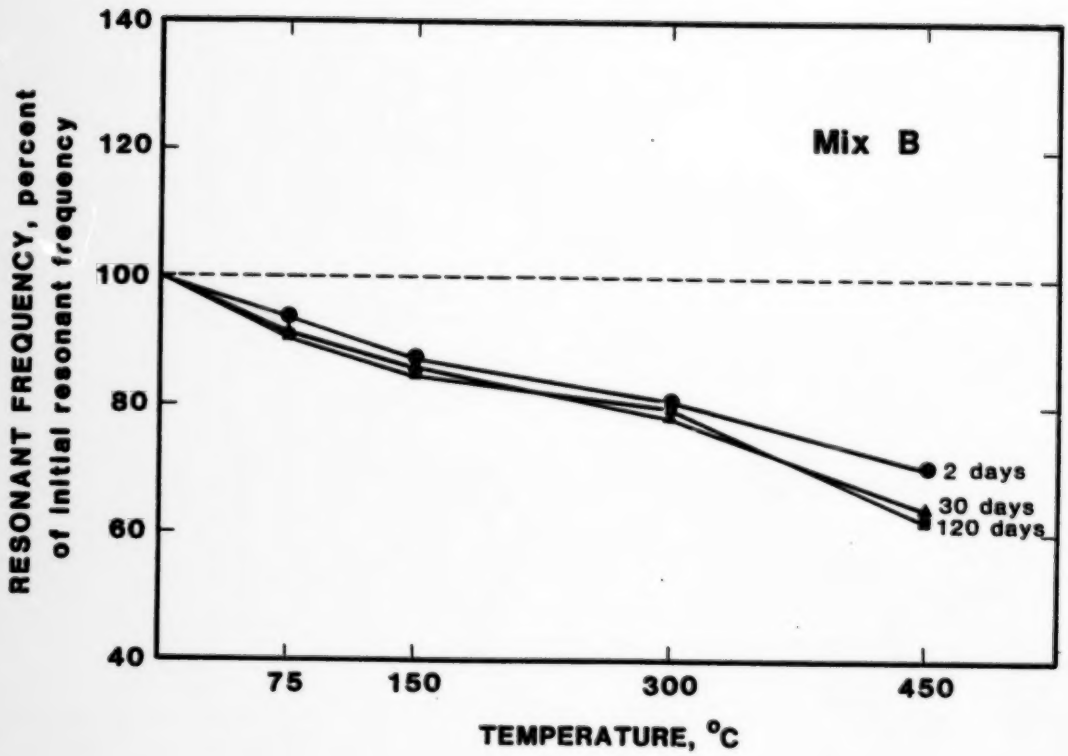

Fig. 10 – Change in resonant frequency during heating: mix B